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Modeling Surges in Navigation Lock Approaches

by Richard I. Stockstill

PURPOSE: The purpose of this Technical Note is to provide basic information regarding the modeling of surges generated during the operation of navigation locks. Accurate modeling of the time varying water-surface slopes is needed to estimate forces exerted on barge trains moored in the lock approaches.

INTRODUCTION: The operation of locks in navigation channels produces surges that can generate forces on moored vessels and lock gates. Wave heights may overtop walls and drawdown may produce insufficient navigation depth. Analyzing surges is difficult with existing analytical technologies and one-dimensional models because minor changes in canal cross section produce partial reflections. The effect of channel planform irregularities is difficult to quantify and lends itself to a two-dimensional (2D) model capable of resolving these boundary shapes. Vessel transit time through a project can be reduced if the tow is allowed to moor in the immediate lock approach during lock chamber operations. Also, the construction of new locks in the vicinity of existing projects may be constrained due to surges produced from normal operation of the existing lock. A limit on allowable lock operation time may be required during construction periods.

Surges resulting from the emptying of the proposed New Kentucky Lock are modeled as a demonstration of the capability of a 2D model to capture the rapidly varying waves and currents in the lower approach during lock emptying operations.

APPROACH: The 2D depth-averaged flow model, HIVEL2D, is used to model the unsteady velocities and water-surface elevations in lower lock approaches resulting from lock emptying operations. The HIVEL2D model was chosen for this study because it is designed to provide numerically stable solutions for advection-dominated flow containing large gradients in the flow variables. Large gradients in depths and velocities are present in the vicinity of lock outlets during emptying operations. The flow conditions in these areas can vary from no flow to peak discharges of about 566 cu m/sec (20,000 cfs), through a restricted area, in less than 2 min.

Modeling flow conditions in the lower lock approach during lock emptying requires the ability to simulate the time-dependent flow rates that represent the lock emptying hydrograph in the computational model. The HIVEL2D code has been modified to allow specification of time-dependent inflow boundary conditions, allowing the modeling of the lock's lower approach. The time-dependent discharge from the lock outlets is the inflow used to drive the hydrodynamic model. Two different methods are used to simulate the lock discharge. Outflow issuing from discharge outlet manifolds, where there is no horizontal momentum such as an interlaced lateral design, is specified as a point source of mass. The conservation of mass equation was extended to include a change in mass term. This term is a time-dependent scalar value having units of length per time. Values of the change in mass term are chosen so that when applied over the area

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representing the laterals, the product equals the lock discharge. The method assumes no horizontal momentum and currents are generated by the water-surface gradients across the area representing the discharge outlet manifolds and the remaining flow field. The second method uses specification of unit discharge components in the x- and y-directions, as boundary conditions. This input method is associated with lock outlets that have significant horizontal momentum such as outlet buckets. The only changes to the HIVEL2D input are that these unit discharge components are input as functions of time.

APPLICATION: A model investigation was performed for the U. S. Army Engineer District, Nashville, to evaluate the lower approach of the proposed new Kentucky Lock[1] (Stockstill and Hite 1998). The Kentucky Lock is located on the Tennessee River about 32 km (20 miles) southeast of Paducah, KY. The new 366-m (1,200-ft) lock will increase the project's navigation capacity. Details of the lower lock approach are provided in Figure 1. Two alternatives for the lock discharge outlet system were evaluated. Simulations of the flow conditions in the lower approach were performed to evaluate the interlaced lateral and landside channel discharge alternatives. Adverse flow conditions (large streamwise and cross-stream water-surface gradients) in the lower approach may prohibit tows from mooring in this area during lock emptying operations.

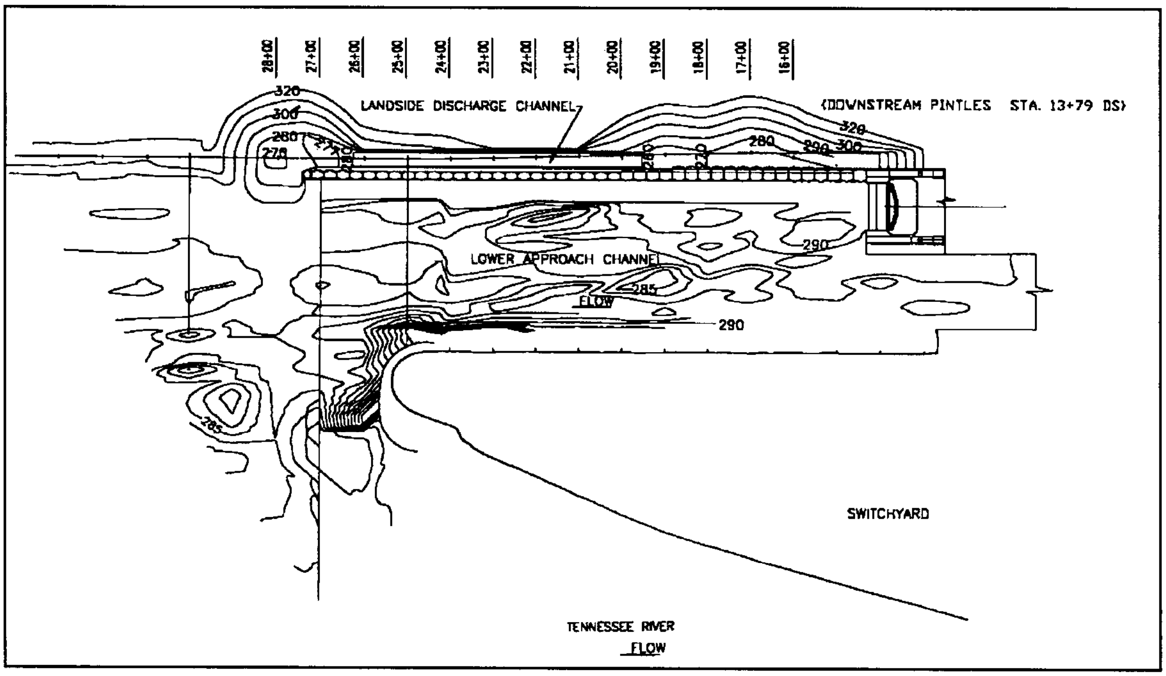

Figure 1. Plan view of the proposed new Kentucky Lock lower approach

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1 Stockstill, R. L., and Hite, J. E. (1998). "Application of a two-dimensional model of hydrodynamics to the lower approach of the new Kentucky Lock, Tennessee River, Kentucky; Numerical model investigation," Technical Report CHL-98-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Lock emptying hydrographs (time-varying outlet discharge), provided by the Nashville District, were used as the inflow boundary conditions to the lower approach model. The variations of water-surface differential, at two selected locations, are shown in Figure 2 for the landside channel discharge alternative. These stage differences at stations 366 m (1,200 ft) apart can be used to estimate the hawser force of a moored 3 by 6 barge arrangement. A positive differential means the upstream water surface is higher than the downstream water surface, and a negative differential indicates the downstream water surface is higher. These simulation results clearly show that the fast lock valve speed (1.5 min) produces significantly larger differentials as compared to a relatively slow valve (6 min). The higher tailwater also reduces the peak differentials as the two curves for the 1.5-min valve illustrates.

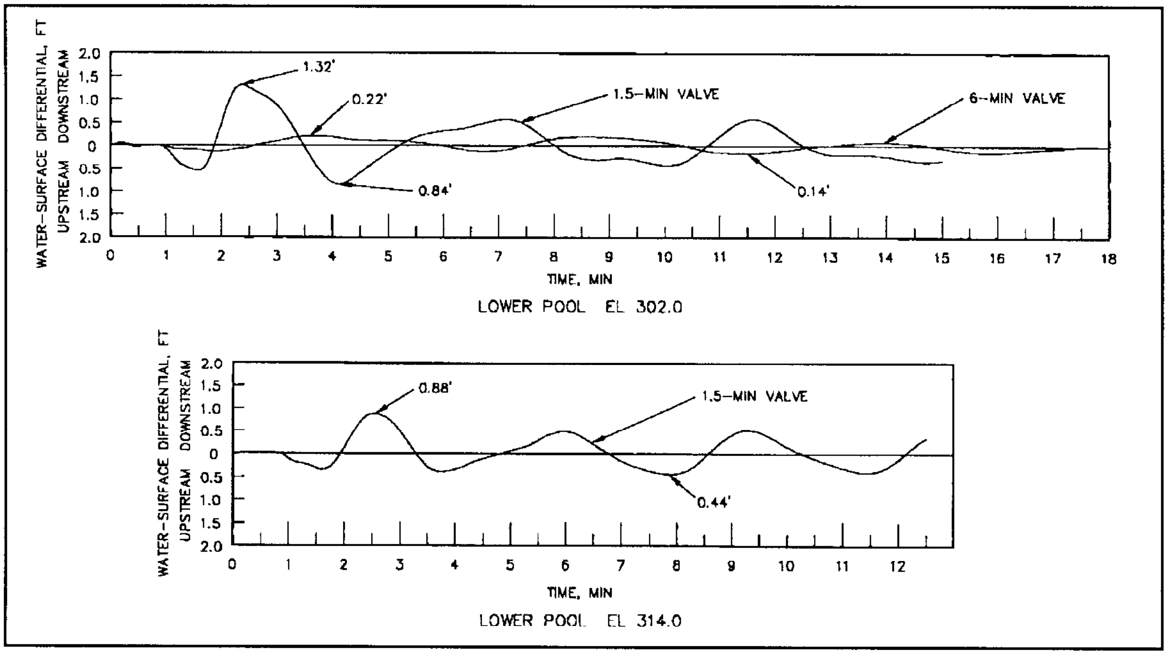

Figure 2. Water-surface differential variations for fast and slow valve speeds and high and low tailwater elevations[1]

Velocity vectors and water-surface contours are displayed in Figure 3 for the landside channel design. The vector plot shows that the landside discharge alternative generates two eddies at the time of peak discharge (1.5 min with a 1.5-min lock valve speed). The water-surface contours show a 1-ft differential between the lower miter gates and the end of the guide wall.

CONCLUSION: A model capable of modeling surges in lower lock approaches has been demonstrated on the proposed new Kentucky Lock discharge outlet design. The time varying water-surface slopes can be used to rank design and valve operation alternatives with regard to forces exerted on a barge train moored in the lower approach for any number of lower pool elevations.

[1] All elevation (el) cited herein are in feet referenced to the National Geodetic Vertical datum (NGVD) (to convert feet to meters, multiply by 0.3048).

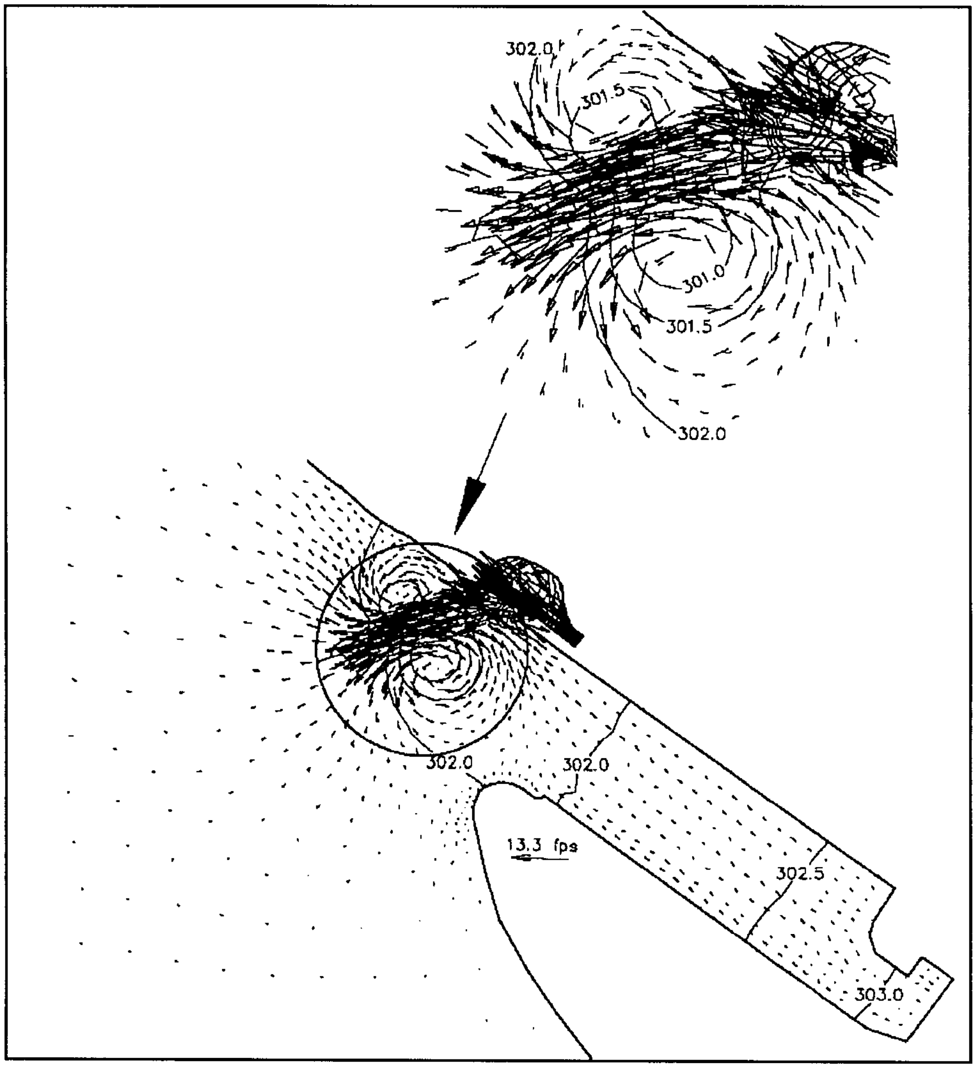

Figure 3. Velocity vectors and water-surface contours at 1.5 min during lock emptying, lower pool el 302, 1.5-min valve

Future efforts will be directed toward extending the model to provide time-dependent outflow boundary conditions so that upper lock approaches may be modeled. Another area of research needed is the inclusion of vessel effects on the flow field. If this vessel/fluid interaction were included in the flow model, the forces exerted on a moored barge train could be more accurately predicted.

ADDITIONAL INFORMATION: For additional information contact Dr. Richard L. Stockstill, Navigation Branch, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center at 601-634-4251 or e-mail *stocksr@wes.army.mil.*